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Establishing bankability for high performance, cost reducing SkyTrough parabolic trough solar collector

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Abstract

Concentrating solar power (CSP) holds great promise for providing clean, economical and dispatchable thermal energy for use in electricity production via a turbine generator or directly in industrial processes. In particular, parabolic trough solar power plants have been operating in the Mojave Desert since the 1980s, with power purchase agreements now in the $0.06/kWh range, giving ample evidence that they will carry on delivering electricity for decades, long after their capital investment is paid off. Since 2005, nearly 2 GW of parabolic trough solar power plants have been installed around the world under various incentive and grant programs that make them financially viable. For this technology to reach its full market potential, it is necessary to drive down the cost of energy produced. This will be achieved by increasing efficiency, increasing volume of component production, decreasing cost of installation, and decreasing cost of finance. SkyFuel has addressed each of these areas for cost reduction in our optimized SkyTrough® design. In this paper we describe our approach and show the validated benefits.

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1. Introduction

Parabolic trough solar technology has proved reliable over the past 25 years in the Mojave Desert, and is now understood to offer greater value compared to other forms of renewable energy, due to the smooth production of power and dispatchability available from thermal storage [1]. To claim its share of the energy market, the cost of energy produced by the solar field must be reduced. To reduce costs, designs must be innovative and challenge the

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Fig. 1. SkyTrough 1 MWth Loop at SEGS II in Daggett, California.

status quo. Innovation introduces risk and makes the technology potentially more difficult to finance. This vicious cycle can be broken by a methodical and strategic regimen of innovation, testing, demonstration, documentation, and use of financial risk mitigation tools from multiple sources including the re-insurance industry.

SkyFuel designed SkyTrough to significantly lower the cost of thermal energy produced by parabolic trough solar collectors and facilitate the commercial expansion of concentrating solar power plants. Every aspect of the integrated SkyFuel design was optimized to increase performance and lower cost. This optimized design is made possible by the use of ReflecTech®PLUS mirror film in place of traditional glass mirror facets, and the use of a lightweight aluminum space frame. The aluminum space frame snaps together with no jig or assembly house required, and the large monolithic mirror panels slide into precise parabolic tracks and require no alignment. Installation is much faster and simpler, reducing costs dramatically even while increasing performance compared to that of time-proven glass-based parabolic troughs such as the EuroTrough. All components are also suitable for large scale automated manufacturing in existing plants. The cost savings achieved by SkyTrough are distributed between equipment cost, installation cost, operating parasitics and maintenance, and performance improvements. Comparisons are presented between SkyTrough and EuroTrough ET150 for material costs, EPC costs (balance of field and installation), and the levelized cost of energy (LCOE) using System Advisor Model (SAM) of the National Renewable Energy Lab (NREL).

While parabolic troughs have been operating successfully for many years and projects based on this technology have been the recipient of traditional project financing, there was a perceived risk from SkyFuel's use of ReflecTech mirror film in the SkyTrough, in place of traditional glass mirrors. Previous papers have extensively reviewed comprehensive testing of ReflecTech [2]; field validation of SkyTrough performance [3]; and how these results enabled SkyFuel to offer the most comprehensive warranty in the CSP space [4]. In this paper we extend the time frame of data presented and discuss how a due diligence driven review of the technology allow a leading world-wide evaluator of risk to offer multiple mitigation tools for projects using SkyFuel technology.

Three SkyTrough parabolic trough solar collectors, pictured in Figure 1, were installed at Solar Energy Generating Station II (SEGS II) in Daggett, California at the end of 2009 and placed in operation in February of 2010. The 1 MWth loop provides heat to the 30 MW power block and is operated along with the 28 year old LS-2 solar field. SkyTrough collectors have been delivered to three commercial plants under construction, and demonstration of sustained high performance of the technology at SEGS II was crucial for securing project finance. In this paper we will present three years of data from the SEGS II loop; thermal production and specular reflectance data for ReflecTech mirror panels.

2. Performance of SkyTrough over three years

The methodical validation of the performance of SkyTrough installed at SEGS II in Daggett, California is documented in McMahan et al. [3] in 2010, after less than a year of operation, and in White et al. [4] in 2012, after 18 months of operation. These papers documented the validity of optical and thermal efficiency measurements of a single module at NREL as the basis for performance prediction in the field, and long term performance prediction as the basis of an extended warranty, respectively. This paper doubles the data set to three years. The validated efficiency of SkyTrough in converting sunshine to thermal power is 73.7% at an operating temperature of 350° C.

The SkyTrough loop has continued to operate in conjunction with and on the same schedule as the SEGS II solar field. The actual thermal output has continued to correlate well with the output predicted from the measured DNI and single module efficiency measurement. Three years of data are now available and are shown in Figure 2. The average ratio of measured to predicted thermal output for the three years is 97%. These results continue to support the conclusion reached by McMahan et al. [3]: NREL test results for a single SkyTrough mirror module accurately predict the response of a complete loop.

The reflectors and absorber tubes in the SkyTrough loop are cleaned 4-6 times per year with pressurized, demineralized water.

The SEGS II facility always shuts down for maintenance for the month of January; in 2012, the maintenance included replacement of some parts of the steam turbine and kept the plant closed for all of February and half of March as well. These plant closures explain the lack of data in those time periods.

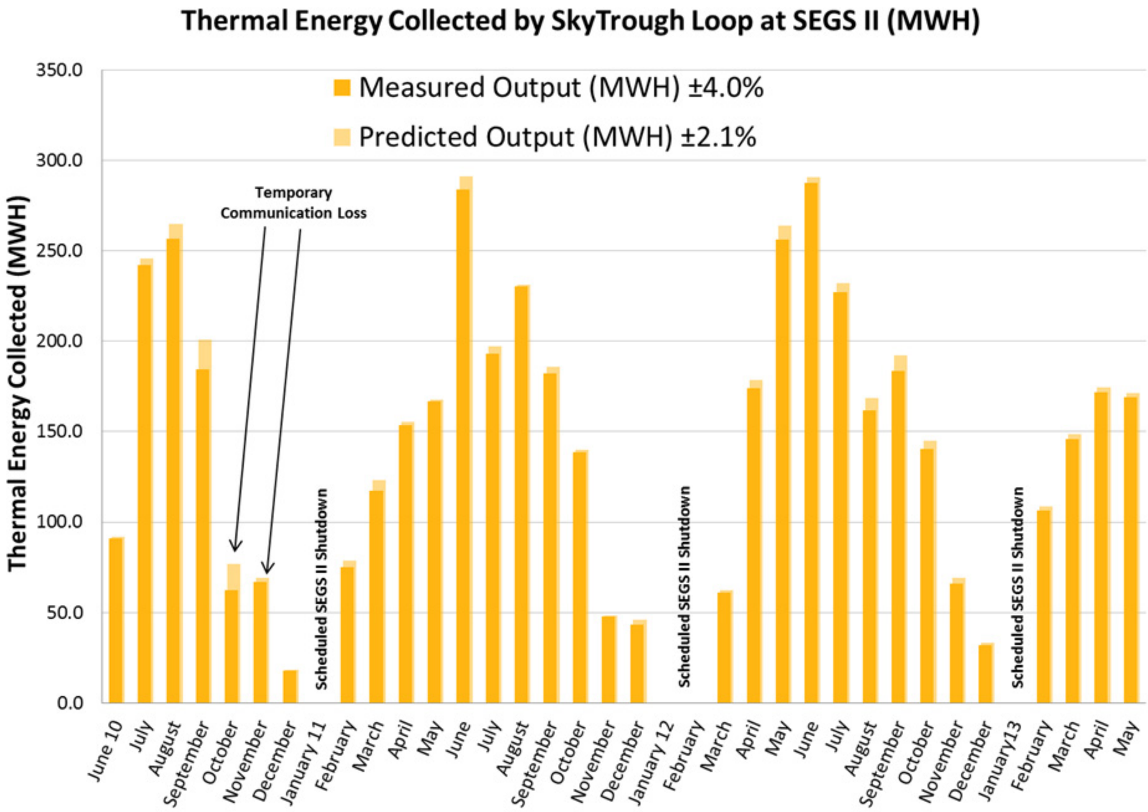

Fig. 2. Thermal energy collected by SkyTrough loop at SEGS II: predicted and actual.

3. Reflectance of ReflecTech mirror film

The operative use and standard test protocol of ReflecTech silvered polymer reflectors in the SkyTrough loop at SEGSII was described in [4], and reflectance measurements for the first eighteen months of operation were presented. That data set is extended to three years in Figure 3. The average clean specular reflectance, measured with a Devices and Services Specular Photometer at a wavelength of 660 nm and with an acceptance angle of 25 mrad, is 93.2%. The reflectance of SkyTrough mirror panels at the SEGS II commercial plant has been maintained, without loss, within normal fluctuations attributed to variation in the thoroughness of cleaning and accuracy of measurement.

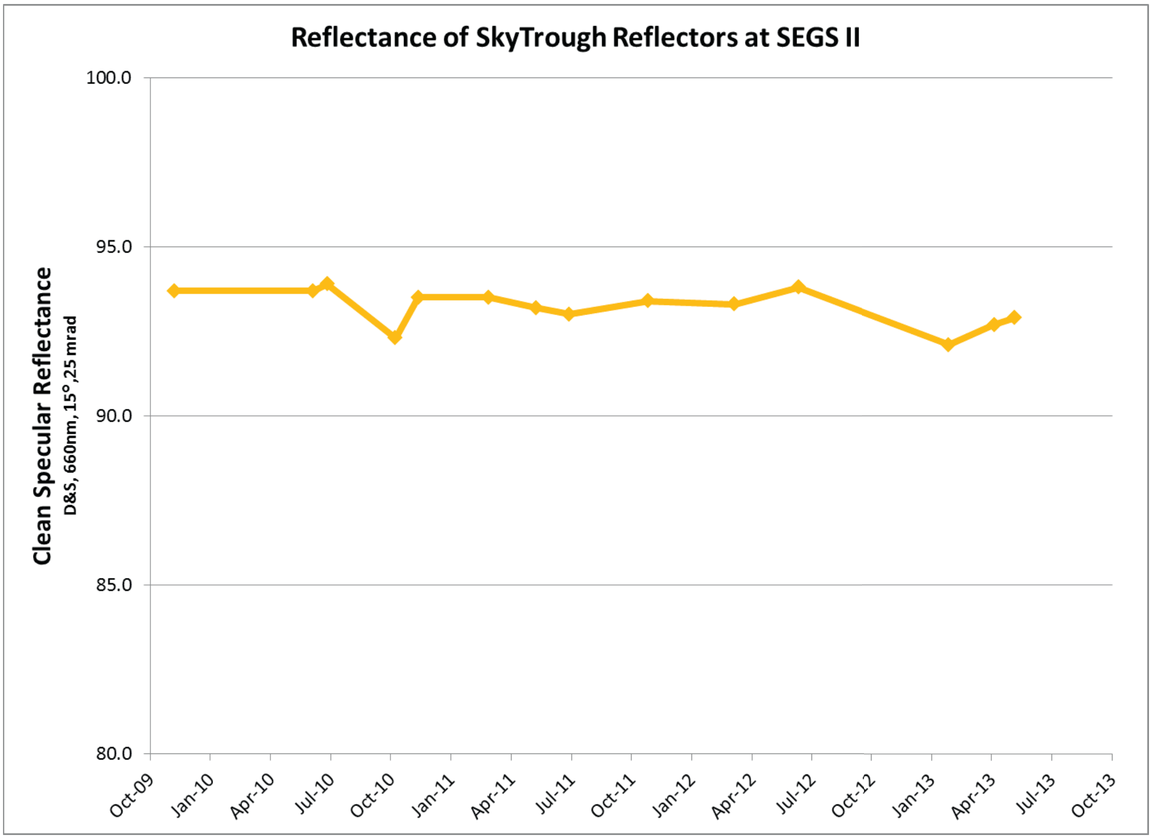

Fig.3. Reflectance of ReflecTech reflectors in SkyTrough loop at SEGS II.

4. Reduced material costs

SkyTrough was engineered to minimize the cost of solar heat produced. In Figure 4, the costs of the components that comprise SkyTrough are compared to those of the EuroTrough 150 (ET-150). Costing information was taken from *Renewable Energy Technologies: Cost Analysis Series, Vol.1: Power Sector* by the International Renewable Energy Agency (IRENA) [5]. This comparison is independent of the costs for installation and balance of field, which contribute an additional 34% cost savings.

SkyTrough's design is based on use of ReflecTech mirror film in place of traditional glass mirror facets. Use of the film enables a cascade of cost-saving, performance-enhancing improvements to the design of the parabolic trough. Per unit aperture area, the ReflecTech reflectors cost less than slumped glass mirror facets. The lighter reflectors and gravity-balanced design mean that the aluminum space frame is significantly lighter than traditional steel torsion box and torque tube designs, and results in reduced cost even when aluminum is more expensive than steel. The SkyTrough design requires fewer (larger) receivers, pylons, trackers, and rotating piping connections, each contributing to reduced overall cost. The extremely accurate SkyTrakker controls package supplied by SkyFuel is optimized for performance tracking and real time reporting in solar field operation. This results in reduced equipment costs, smaller parasitic loads, and decreased operations and maintenance (O&M) costs for the life of the plant. Altogether, the cost for SkyTrough collectors is 36% less than that for EuroTrough 150.

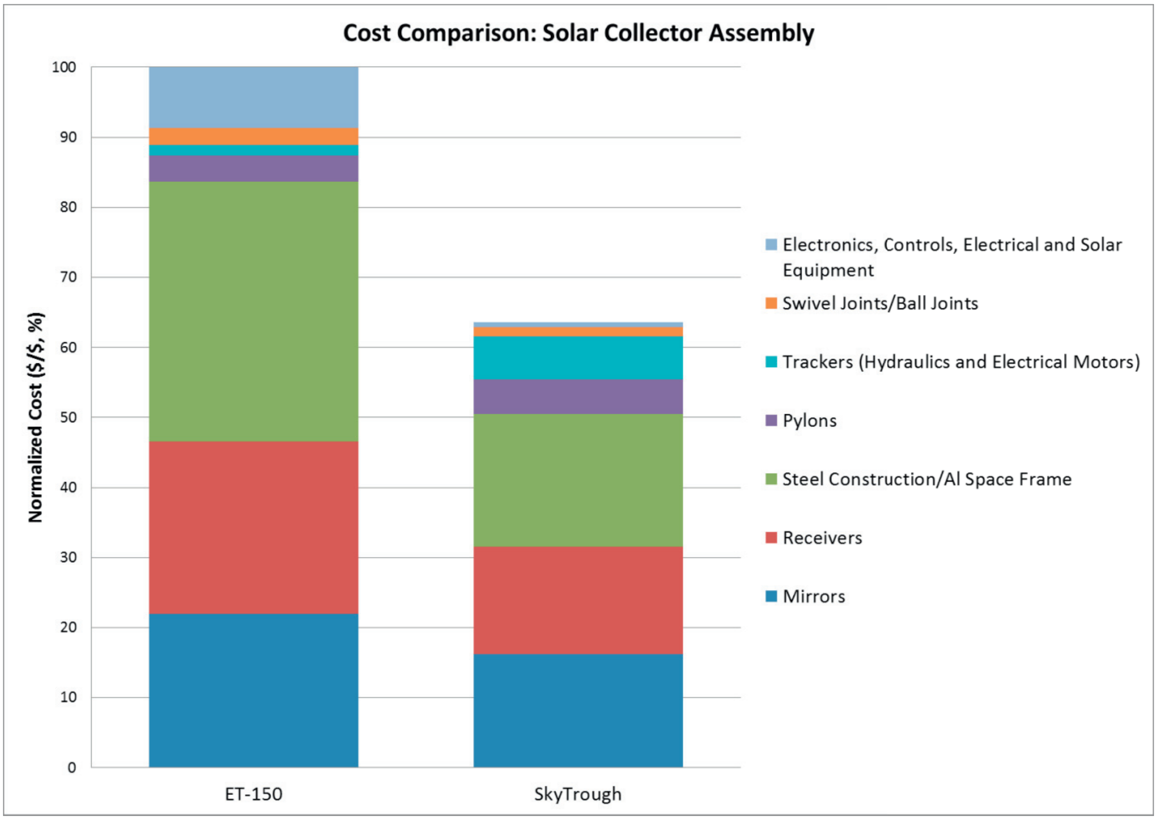

Fig. 4. Comparison between costs for material of SkyTrough and EuroTrough.

5. Reduced balance of field and installation costs

SkyTrough was engineered to minimize the overall cost of solar heat produced; hence, great attention was paid to reduce installation costs. Additional cost savings result from the smaller solar field size needed because more energy is produced per unit of aperture area compared with other parabolic trough technologies. In Figure 5, the installed cost of the solar field minus the collector equipment (i.e. collector installation, heat transfer system equipment, and heat transfer system installation) for a SkyTrough parabolic trough are compared to those of a EuroTrough-150 (ET-150). Costing information was derived from the *CSP Parabolic Trough Pant Cost Assessment* by the WorleyParsons Group, scaled for equivalent thermal output [6].

The basis of the comparison is a solar field sized at a reference condition of 1000 W/m2 to provide heat to run a 50 MW-electric power plant. The greatest savings are seen in the "Solar Field Assembly" slice; at an estimated 133 Man-Hours to install each SkyTrough collector, the savings on labor alone can be as much as 64%. These savings result from the snap-fit design of the frame and the slide-in installation of the reflectors, with no optical adjustment required. The superior optics of the monolithic, ReflecTech mirror film based reflector result in higher sun to heat efficiency, and a smaller solar field for a given thermal output. The smaller field results in reduced costs for site preparation, foundations, field piping, and heat transfer system equipment. Additionally, no assembly tooling or building is needed. Altogether, the balance of field and installation of SkyTrough costs 34% less than that of EuroTrough 150.

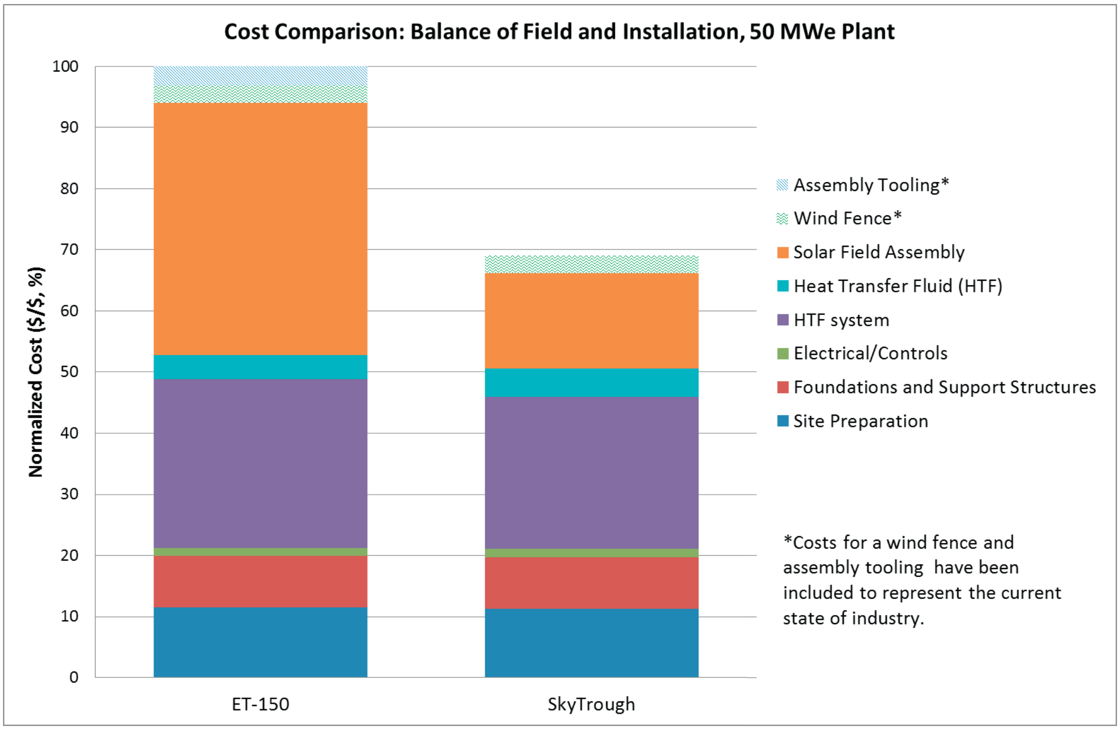

Fig. 5. Comparison between costs for balance of field and installation of SkyTrough and EuroTrough.

6. Lifecycle cost of energy

System Advisor Model (SAM) was used to calculate the lifecycle cost of energy (LCOE) for a 100 MWe plant with three hours of thermal storage in Daggett, California using ET -150 and SkyTrough collectors. Each plant was modeled using standard SAM default values for all financial parameters except collector cost. Installation, operation and maintenance were reduced for the SkyTrough based on the comparison made in Section 5. At $12.86/MWh, the LCOE for the SkyTrough is 17% lower than that of the EuroTrough, at $15.55/MWh.

7. Financial risk mitigation

To make the technology more acceptable to banks for financing, SkyFuel offers extended thermal performance and reflectance warranties on the basis of validated performance described by White et al. [4]. Thermal performance is warranted for five years (at 96% of the output at acceptance test) and reflectance is warranted for twenty years (at 95% for the first ten years and 90% the second ten years). SkyFuel has further leveraged the extensive evidence of the reliability of our technology by securing warranty backing from MunichRe, one of the largest re-insurance firms in the world. MunichRe performed extensive due diligence on the technology, manufacturing process, and system performance, prior to offering full backing of the SkyTrough warranty.

With warranty backing in place for a project, MunichRe will cover most of the remaining financial risk in the project with optional debt service coverage for the project owner. This coverage guarantees the portion of the debt service attributed to the solar field and removes any risk that SkyFuel is unable to cure a warranty claim. The bank is then able to reduce the interest rate on the loan, which typically offsets the cost of the insurance coverage. The result is a no / low cost path to bankability for an innovative, cost-reducing parabolic trough.

8. Conclusions

Three years of performance data from the SkyTrough loop at SEGSII demonstrate that SkyFuel's technology is high performing in a predictable and reliable manner. Reflectance measurements of ReflecTech mirror film have shown no degradation after more than three years of operation in a commercial environment.

SkyTrough solar collectors cost 36% less than externally documented traditional glass and steel parabolic trough collectors and 34% less to install, including material costs of the balance of field.

On the basis of predictable high performance, SkyFuel is able to offer extended thermal performance and reflectance warranties, and MunichRe is able to offer SkyFuel the only parabolic trough warranty coverage in the industry. Based on demonstrated significant project cost savings and the mitigated technology risk provided by MunichRe's optional debt service coverage for project owners, SkyFuel now offers to the energy market an excellent and bankable option for reliable and affordable concentrating solar power, and the ingredients necessary to build out the market potential for clean, economic, and dispatchable power from the sun.

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